THE LATENT TIME OF THE KNEE-JERK

BY

E. CAREY APPLEGARTH, B. A., PH. D., M. D.

A THESIS

PRESENTED FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN THE JOHNS HOPKINS UNIVERSITY

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From the time of its study by Westphal and Erb in 1875 the knee-phenomenon has been a subject of increasing interest to the physician, to physiologists, and to the psychologist. Its clinical usefulness has been especially recognized in the United States and has led to numerous investigations intended to solve questions of special interest to the physician. There is, perhaps, no other subject concerning which the scientific physician has during late years contributed so much to physiological knowledge; nor any which so well illustrates the mutual dependence of clinical observation and physiological experiment.

Most of the work in this line of inquiry has been done on man, and usually with the aim to determine the absence, presence, or amount of the knee-jerk under various conditions, normal and pathological. The accurate measurement of the *time element* is extremely difficult in human beings, and our knowledge of this element still far from satisfactory; this fact led me to the investigation now described. Without attempting here an exhaustive review of the literature bearing upon the latent time of the knee-phenomenon (or knee-jerk as many prefer to call it), a brief account of previous investigations in regard to the *time* involved will be useful.

Tschirjew[1] in 1878 undertook the solution of the problem in the following way. Over the ligamentum patellæ was bound a piece of rubber on which a bit of thin sheet copper was fastened. A conducting wire ran from this plate to an electric signal connected with a Daniell cell. From the same battery extended another wire to the metallic end of a percussion hammer, so that at the delivery of the tap upon the ligament, or rather upon the copper plate over the latter, the current was closed through the

[1] Tschirjew, Arch. f. Psych. 8, 1878, p. 689.

signal. A contact key placed over the m. quadriceps femoris, on contraction of the muscle, directed a current from another Daniell cell through a second electric signal. Both signals, and a Marey's chronograph making one hundred double vibrations per second, wrote in the same vertical line on a revolving drum. The signals were so adjusted that their respective electrical latent periods were equal. For the results obtained by Tschirjew and others see table I, p. 6.

In the succeeding year Gowers[1] measured the knee-jerk latency by attaching to the foot a pen which traced the movement of the foot on a revolving drum, on which a chronograph pen also wrote. No mention is made of the manner of marking the instant of the tap on the ligament. Waller,[2] in 1880, caused the latent time of the knee-jerk to be "recorded by a lever-bearing tympanum, in connection with an explorer fixed on the muscle. A tube branching off the tympanum tube and crossing the tendon was first employed to record percussion. But the jar communicated to the explorer by the percussion is sufficient to record its instant." He makes use of a revolving drum, the quick rate of which was three mm. in one one-hundredth of a second. The time tracing was effected by a tuning fork making one hundred double vibrations per second.

Eulenburg[3] employed the vibrating glass plate of Landois, and Brondgeest's pansphygmograph somewhat modified. The tuning fork being struck, in the same vertical line upon the blackened plate, so set in motion, two levers traced out their respective curves, being governed by tambours provided with 90–96 cm. rubber tubing extending to two receiving tambours—one on the m. quadriceps femoris and the other upon the knee. The one fastened on the thigh was an ordinary Upham's cup, 4½ cm. diameter, bounded on the lower side by an elastic membrane with the customary button for resting upon the muscle. The one strapped around the knee, however, consisted of a brass ring, 3 cm. in diameter, over the upper and lower surfaces of which were

[1] Gowers, Med. Chir. Transactions, Vol. LXII, 1879, p. 269.

[2] Waller, Brain, July, 1880, p. 179.

[3] Eulenburg, Neurol. Centralbl. 1, 1882, S. 3; and Zeitschrift f. klinische Med. 4, 1882, S. 179.

tied elastic membranes. In an experiment, the vibrating glass being set in motion by the assistant, the ligamentum patellæ of the subject is struck by the operator's hand; the wave of compression thus originated in the tambour covering the knee is transmitted to the recording tambour: the thickening of the muscles, which contract to produce the knee-jerk, initiates from the Upham's cup a similar chain of events; and the latent time of the contraction may at once be read off in swings of the tuning fork. The time (0.003″) taken by the wave to traverse the tubing connecting the receiving with the recording tambours is eliminated by having the same length of tubing in each case.

Rosenheim[1] attacked the problem with an instrument specially devised for the purpose. It consists of two uprights, one immovably attached near its upper extremity to the bottom of a V-shaped collar, and the other mobile around a Charnier's joint in the two arms of the latter. A little above this joint there is on the one upright a plate for making electrical contact with a screw carried by the other. The uprights may be adjusted by means of a spring situated below the joint. On the lower edge of each upright is a ring, to which is secured the band strapping the instrument to the leg. When the muscle contracts, contact is broken between the screw and the corresponding plate, and an electric signal marks this instant on a revolving drum, whose quick rate equals one metre of paper in thirteen seconds. The tap upon the patella is registered by another signal, the action of which depends upon a blow from a percussion hammer in connection with a Daniell cell, upon a piece of copper or tin foil, also in connection with the battery, and placed over the ligament.

The results of these investigators along with those of A. de Watteville,[2] who availed himself of Waller's method, and those of Brissaud,[3] who used an electric signal for recording the tap, and a Mendelssohn's myograph to record the contraction of the muscle, may be tabulated as follows:

[1] Rosenheim, Arch. f. Psychiatrie, XIV, 1884, S. 184.
[2] A. de Watteville, Brain, July, 1882, Vol. 5, p. 287.
[3] Brissaud, Publications du Progrès Med., Paris, 1880, p. 206.

TABLE I.

Worker.	Subjects.	Observations.	Latency.
Tschirjew,	2 patients.	146	0.0595″
Gowers,	2 normal persons. 1 case of lateral sclerosis.	?	0.100
Waller,[1]	12 patients.	?	0.035
Brissaud,	? normal.	?	0.050
	? hemiplegia.		0.015
Eulenburg,	100 students.	?	0.024
A. de Watteville,	1 patient.	?	0.025
Rosenheim,	4 individuals.	?	0.04313
	cases of hemiplegia.	?	0.025
	10 rabbits: normal.	?	0.033
	10 rabbits: brain excluded.	?	0.023

With the exception of that of Gowers, it will be seen that in all the above contributions to the literature of the subject in hand, the contraction of the m. quadriceps femoris has been recorded by implements which depend for their efficiency upon the swelling of the muscle as it contracts. Remembering how difficult it is, even with an isolated muscle, to obtain apparatus sufficiently delicate to render manifest the initial stage of contraction, and having in mind the importance of the question as to whether the knee phenomenon is or is not a reflex action, it seemed desirable to make further experiments with more accurate methods.

I have chosen dogs as the subjects of my research. In a later paper I hope to discuss the matter more fully and to give observations on the human subject.

In the present investigation five hundred and eighty experiments were made on thirty-two dates upon three bitches, which for the sake of convenience may be designated A, B, C. Of these experiments, one hundred and one were performed upon A, two hundred and ninety-one on B, and one hundred and eighty-eight on C. A and B had their spinal cords severed at the level of the last dorsal vertebra, C was normal. All three were small and as similar as it was possible to obtain them.

[1] Since writing the above I notice Waller has published a more recent research in the Journal of Physiology, Vol. XI, p. 384. With improved apparatus he finds that 0.012″ intervenes between the instant of percussion upon a rabbit's tendon and the resulting muscular contraction. Deducting 0.005″ for the mechanical lost time, and adding 0.001″ to counterbalance the lost time of the Despretz signal, he obtains the corrected interval 0.008″.

A was operated upon with aseptic precautions during the first week of April, 1889. She recovered well and remained strong and healthy; but owing to other duties it was impossible for me to experiment upon her knee-jerk until the following January. Towards the latter part of February (1890), in consequence of an attack of mange, a lotion was applied to her skin, which she licked off, poisoning herself. The autopsy, made with the kind assistance of Dr. W. T. Councilman of the Johns Hopkins Hospital, showed the severed spinal cord was reunited by dense fibrous tissue. Beyond obvious degeneration of certain nerve tracts (which had been going on for eleven months prior to death) no pathological change was manifest in the spinal cord. The whole cerebro-spinal axis was carefully preserved for future microscopical examination.

As the cord of A was cut above the centres of defecation and micturition, there was no *à priori* reason why these natural actions should not be reflexly excited, and this conclusion was amply justified by the facts. As Goltz found, sponging the anus, pinching the tail, and even the dragging of the hinder parts about by the animal itself while it crawled on its fore limbs, proved effectual in leading to evacuation of the bladder and rectum. Whenever micturition or defecation occurred there was an accompanying train of reflexes involving the muscles of the tail and hind legs.

The animal was fed and exercised with great regularity. Her exercise consisted in permitting her, while I supported her hind limbs off the floor, to run or walk where and how she liked for fifteen to thirty minutes in the morning, the same at noon, and one-half to one hour at night. She was always at liberty, when not at exercise, and could crawl around as much as she pleased. In addition the muscles of the paralysed legs were exercised by electric stimuli, and from the date on which the knee-jerk observations commenced almost daily experimentation added its quota towards keeping the muscles in healthy condition. The expenditure of time and energy involved in caring for this animal during so many months was very great, but in no other way can good health be secured to a dog with severed spinal cord, and

the good health of the animal's muscles and nerves was essential to me.

B was operated upon the day following the death of A, and was used for experimentation upon her knee-jerk two weeks later. Her health remained good. The same care was taken as with A.

C, as stated above, was normal, and as far as possible kept under the same conditions as were A and B.

All three dogs were young, and were taught without much difficulty to lie quiet when experimented on.

A thin cushion placed on a board formed a bed. From one side of the boards two straps extended. One strap passed over the neck and the other over the body just posterior to the forelegs. This bed was not disagreeable; indeed, the dogs appeared to find it comfortable, since they would often go to sleep on it.

While the trunk was thus kept quiet the leg (in all cases the right) whose knee-jerk was to be investigated was held in a large retort-holder which could be adjusted to fit snugly, binding upon the condyles of the femur with pressure just sufficient to hold the leg securely. The upright carrying this holder was clamped to the table, so that the only movement that could take place, when the ligamentum patellæ was struck, was that of the tibia on the knee-joint. The foot was strapped in two places, not too firmly, to a splint extending from the toes to a point a little past the tarsus.

This splint is of wood one inch thick, three long, one broad, and has its upper surface concave. At each end there are two buttons, one on each side, for leather straps hanging from a hook which swings in an iron thimble at the end of a cord suspended from the ceiling. At the distal end of the splint is a binding screw, into the top of which is soldered a stiff platinum wire. The latter may be made to press against a contact plate of platinum that is fastened upon a block of vulcanite, which in turn slides upon an upright similar to that of a Roy's universal holder. A Pfeil signal is included in this circuit.

Over the ligamentum patellæ was attached, by means of adhesive plaster, a thin narrow strip of brass covered with platinum. Upon this strip of brass, which also stands in electrical connection with a Pfeil signal, impinges a hammer the exact duplicate of

Lombard's,[1] with the exception that the head is very much lighter, weighing only ten grams, and is insulated from the handle, and that instead of the catch holding the head up is an electro-magnet performing the same office. This hammer, being in the same circuit as the strip of brass fitting snugly over the knee, causes, when it strikes the latter, a closure of the current, which instant the signal records. The contact edge of the head of the hammer is covered with platinum, as in all other cases where instantaneous electrical connection was desired. Throughout the whole research a very light tap was used, due to a fall of the hammer of two degrees of the circle.

The exact arrangement of these various parts can best be understood by reference to the diagram represented in Fig. 3, Plate XI. *B* is a battery of two large Daniell cells, while *T* is a break mechanism or trigger like that of a pendulum myograph. When *T* is up against the screw, and *H* is not touching *K*, the current finds a complete circuit through the electro-magnet *M* back to the battery. When, however, the trigger is down, as shown in the diagram, the current can no longer flow through *M*, but is compelled to pass through *H*, the hammer, *K*, the knee piece, *S*, the signal, and thence back to the battery. But this circuit is only closed when *H* touches *K*.

Fig. 2, Plate XI, shows in a diagrammatic way the circuit of the other signal. *B* is a battery of one large Daniell cell. *P* is the stiff platinum wire making contact with *C*. When *P* is pressing upon *C* the current flows from the battery to *P*, through the contact plate *C* and back to the battery. When, however, contact is broken between *P* and *C* the current must pass through *wr*, which is of very fine wire, to the signal *S*, and back to the battery. *K* is simply a key which opens this circuit when desired.

The signals, as mentioned above, are of the same make; they write in the same vertical line on the smoked glass plate of the pendulum myograph described by Sewall,[2] and are placed upon a supporting table which can be screwed up until the writing points of the levers just touch the blackened plate. The latent period

[1] Lombard, Amer. Journal of Psychology, Vol. I, 1887, p. 5.
[2] Sewall, Jour. Physiol., Vol. II, p. 164.

of each was carefully traced on the myograph plate, which for the purpose was made to swing through an arc of displacement 646.8 mm., with therefore a velocity of 1 mm. in 0.000492″ as it passes the writing point of the signal. The difference in the time equivalents of the signals was found to be 0.00008″.

After trying fish-bones, glass drawn out to a very fine point and other objects, I finally decided on exceedingly delicate cambric needles as most satisfactory for the writing points.

The pendulum myograph in use in our laboratory beats true seconds, and swung, in the present inquiry, through an arc of displacement of 220 mm. Consequently if v equals the velocity of the centre of the plate as it passes the zero point of fixed scale corresponding to the middle of the swing of the pendulum, ch the chord of the arc of displacement of the centre of gravity of the pendulum, g the intensity of gravity, and l the length of a second's pendulum at the place in question, then the formula

$$v = ch\sqrt{\frac{g}{l}}$$

gives at once the desired information. In this way the rate was calculated to be 1 mm. in 0.001446.″ As a matter of fact it was found that this rate did not measurably vary for the first two centimeters on each side of the central line of the plate, but nevertheless a tuning fork making 200 double vibrations per second was from time to time employed as a control.

The actual order of each experiment has been as follows: The dog having been placed on the bed, its leg is clamped at the knee and its foot strapped to the splint. After the foot has come to its position of rest, the contact plate *C*, Fig. 2, Plate XI, is pushed up against the stiff wire *P* on the splint until the foot is moved forward about an inch, so that considerable pressure is thereby exerted by the wire upon the contact plate. When so arranged, moderate blows on the splint and distal portion of the tibia prove ineffectual in breaking contact. When, however, the hammer excites the knee-jerk by striking on the ligamentum patellæ, contact is broken and the latency of the phenomenon is registered.

I hoped by thus taking advantage of the great leverage of the extensors of the crus to be able to obtain the record of an early, if not the earliest, stage of contraction.

The trigger T, Fig. 1, Plate XI, slides upon the metal micrometer scale of the myograph, and is so placed that when the latter in its swing knocks it, the signal marks near the middle of the plate the instant of the ensuing tap upon the tendon. This position having been secured, all is ready for an experiment.

The following tables give details of a few of the experiments performed in this way. $R_1 - R_2$ represents the distance expressed in mm. from the beginning of the tracing of one signal to the like point of the other's tracing. The second column contains the time equivalents of the given number of mm. (= mm. × 0.001446″), and the third column the equivalents corrected for difference in latency of the two signals (= [mm. × 0.001446″] + 0.00008″).

TABLE II.

Jan. 30, 1890. Bitch A. Cloudy. External temperature 9° C. Room temperature 20° C. Dog exercised but not fed. Began 9.30 A. M. Observations made every minute.

$R_1 - R_2$.	Time.	Corrected Time.
5.3	0.00766″	0.00774″
7.2	0.01041	0.01049
9.0	0.01301	0.01309
7.2	0.01041	0.01049
7.8	0.01128	0.01136
7.1	0.01027	0.01035
8.4	0.01215	0.01223
7.3	0.01056	0.01064
9.0	0.01301	0.01309
5.7	0.00824	0.00832
8.8	0.01272	0.01280
6.4	0.00925	0.00933
5.8	0.00839	0.00847
8.8	0.01272	0.01280
6.1	0.00882	0.00890

Average, 0.01060″
Corrected average, 0.01068″

TABLE III.

March 25, 1890. B. Cloudy. External temperature 3.5° C. Room temperature 25° C. Dog exercised but not fed. Began 9.15 A. M. Observations made every minute.

$R_1 - R_2$.	Time.	Corrected Time.
9.5	0.01374″	0.01382″
6.5	0.00940	0.00948
7.8	0.01128	0.01136
7.2	0.01041	0.01049
7.9	0.01142	0.01150
6.0	0.00868	0.00876
9.8	0.01417	0.01425
8.2	0.01186	0.01194
9.4	0.01359	0.01367
8.8	0.01272	0.01280
7.9	0.01142	0.01150
7.4	0.01070	0.01078
7.5	0.01085	0.01093
6.8	0.00983	0.00991
6.1	0.00882	0.00890
6.8	0.00983	0.00991
6.4	0.00925	0.00933
8.2	0.01186	0.01194
6.1	0.00882	0.00890

Average, 0.01098″
Corrected average, 0.01106″

Table IV.

March 24. C. Clear. External temperature 6° C. Room temperature 23° C. Dog exercised but not fed. Began 12 M. Observations made every minute.

$R_1 - R_2$.	Time.	Corrected Time.
7.2	0.01041″	0.01049″
6.9	0.00998	0.01006
9.0	0.01301	0.01309
9.8	0.01417	0.01525
9.1	0.01316	0.01324
9.6	0.01388	0.01396
10.4	0.01504	0.01512
8.9	0.01287	0.01295
9.5	0.01374	0.01382
8.8	0.01272	0.01280
10.1	0.01460	0.01468
8.0	0.01158	0.01166
9.2	0.01330	0.01338
10.2	0.01475	0.01483
8.3	0.01200	0.01208
10.5	0.01518	0.01526
9.2	0.01330	0.01338
9.5	0.01374	0.01382

Average, 0.01320″
Corrected average, 0.01328′

After doing a number of experiments in this way it occurred to me to test these results by causing the knee-jerk to make contact. Of course some time must be lost hereby, but nevertheless the averages should be approximately equal, *caeteris paribus*. The only change in the apparatus necessary for this purpose was to dispense with the resistance circuit *wr*, Fig. 2, and put the signal in the primary circuit. Now the contact plate *C*, Fig. 2, is placed in front of *P* at a distance of 1 mm., and an upright is clamped to the table back of the splint, so that the leg may have exactly the same amount of flexion at the beginning of each experiment. The following tables give a few of the protocols so obtained.

TABLE V.

March 19, 1890. B. Cloudy. External temperature 5° C. Room temperature 22° C. Began 10 A. M. Observations every minute.

R_1—R_2.	Time.	Corrected Time.
9.8	0.01417″	0.01425″
9.6	0.01388	0.01396
9.2	0.01330	0.01338
9.5	0.01374	0.01382
10.5	0.01518	0.01526
5.0	0.00723	0.00731
8.0	0.01157	0.01165
5.2	0.00752	0.00760
6.1	0.00882	0.00890
8.8	0.01272	0.01280
12.5	0.01806	0.01814
9.0	0.01301	0.01309
5.0	0.00723	0.00731
5.8	0.00839	0.00847
7.6	0.01099	0.01107
8.0	0.01157	0.01165
10.2	0.01475	0.01483

Average, 0.01189″
Corrected average, 0.01197″

TABLE VI.

March 20, 1890. C. Cloudy. External temperature 7° C. Room temperature 22° C. Began 2 P. M. Observations every minute.

R_1-R_2.	Time.	Corrected Time.
17.5	0.02521″	0.02529″
10.6	0.01533	0.01541
12.0	9.01735	0.01743
13.0	0.01880	0.01888
9.0	0.01301	0.01309
8.8	0.01272	0.01280
8.5	0.01230	0.01238
9.8	0.01417	0.01425
13.6	0.01967	0.01975
11.0	0.01590	0.01598
16.5	0.02386	0.02394

Average, 0.01712″
Corrected average, 0.01720″

Desiring now to apply the method depending upon the thickening of the muscle as it contracts, a piece of brass three mm. square was bound over the m. quadriceps femoris by an elastic band. Soldered to this plate were a copper wire, leading to the battery, and a stiff platinum wire, extending vertically upwards. Near its free end the latter was bent at right angles, and by means of a micrometer screw a sliding stage could be raised up under the horizontal arm until firm yet delicate contact was made. The connections with the stage working on the micrometer screw were the same as with *P*, Fig. 2, so that, as soon as the muscle contracted, the circuit was opened and the signal recorded. Moderate shocks on the splint and body did not suffice to break contact.

The following are some of the results furnished by this method.

Table VII.

March 21, 1890. B. Cloudy. External temperature 12° C. Room temperature 22° C. Fed at 2 P. M. Began 5 P. M. Observations half a minute apart.

R_1-R_2.	Time.	Corrected Time.
12.5	0.01808″	0.01826″
11.8	0.01706	0.01714
6.4	0.00925	0.00933
7.0	0.01012	0.01020
7.5	0.01085	0.01093
7.2	0.01041	0.01049
14.9	0.02155	0.02163

R_1-R_2.	Time.	Corrected Time.
11.5	0.01663″	0.01671″
8.8	0.01272	0.01280
9.2	0.01330	0.01338
8.8	0.01272	0.01280
16.0	0.02314	0.02322
12.4	0.01793	0.01801
9.5	0.01374	0.01382
9.8	0.01417	0.01425
9.6	0.01388	0.01396
10.2	0.01475	0.01483
11.1	0.01605	0.01613
10.2	0.01475	0.01483
10.5	0.01518	0.01526
10.1	0.01460	0.01468
11.0	0.01591	0.01599
13.5	0.01952	0.01960
9.1	0.01316	0.01324
10.0	0.01446	0.01454
9.2	0.01330	0.01338
9.9	0.01432	0.01440
10.5	0.01518	0.01526
6.5	0.00940	0.00948
8.8	0.01272	0.001280
9.6	0.01388	0.01396
7.6	0.01099	0.01107
9.0	0.01301	0.01309
9.5	0.01374	0.01382
10.2	0.01475	0.01483
9.8	0.01417	0.01425

Averagè, 0.01443″
Corrected average, 0.01451″

Table VIII.

March 22, 1890. C. Rain. External temperature 10° C. Room temperature 22° C. Fed 12 M. Began 5.30 P. M. Observations every minute.

R_1-R_2.	Time.	Corrected Time.
10.4	0.01504″	0.01512″
14.6	0.02111	0.02119
13.5	0.01952	0.01960
15.2	0.02298	0.02306
9.0	0.01301	0.01309
15.5	0.02241	0.02249
16.8	0.02429	0.02437
13.0	0.01880	0.01888

R_1-R_2.	Time.	Corrected Time.
14.8	0.02140″	0.02148″
15.0	0.02169	0.02177
9.9	0.01432	0.01440
13.0	0.01880	0.01888
18.3	0.01923	0.01931
14.2	0.02053	0.02061
11.2	0.01620	0.01628

Average, 0.01928″
Corrected average, 0.01936″

The results by averages of all the experiments by each method may be tabulated as follows: By the first method where the knee-jerk caused interruption of the electric current the average latent time in case of A and B was 0.010″, while with C it was 0.014. By the second method above given the average for B was 0.015″, while for C 0.02. By the third method where the registration of the signals depended upon the thickening of the muscles, the average latent time for B was 0.016″, while for C it was 0.020.

From a comparison of these results it seems probable that the latency of the knee-jerk of the dog, as obtained by the electrical method, is not over 0.014″–0.020″.

In applying the second method, as above given, it was frequently noticed that if the distance between *C* and *P*, Fig. 2, Plate XI, was over 1 mm., say 1½–2 mm., the corresponding difference in time became excessively disproportionate, in fact almost equivalent to the time of a superficial reflex. The following table will illustrate this.

TABLE IX.

March 20, 1890. C. Cloudy. External temperature 5° C. Room temperature 22° C. Exercised and fed. Began 2 P. M. Observations made every minute. Distance of *C* from *P* 2 mm.

R_1-R_2.	Time.	Corrected Time.
34.9	0.05047″	0.05055″
33.6	0.04867	0.04875
40.9	0.05914	0.05922
42.8	0.06189	0.06197
38.2	0.05522	0.05530
43.2	0.06247	0.06255
41.0	0.05929	0.05937
41.4	0.05986	0.05994
40.2	0.05813	0.05821

Average, 0.05724″
Corrected average, 0.05732″

whereas, the average of a number of time measurements of skin reflexes elicited by electrical stimulation applied to the toe of A was 0.07141″. This at once reminds us of what Gowers observed, namely, that when the ligamentum patellæ was struck the curve traced by the foot left the abscissa very soon, but the true contraction of the muscle followed at a somewhat later period.

It will be seen also that by each method the latency of the knee-jerk is less in the dogs with their spinal cords cut than in the normal one. This is in keeping with results previously obtained, and tends to confirm the view that the brain is one of the important factors concerned in the time of the phenomenon.

Lombard found the extent of the knee-jerk was very profoundly influenced by the emotions, variations of weather and the like, and it seemed of interest to me whether such changes involved corresponding differences in the time. In this respect, however, my results were not quite satisfactory, and after the first few experiments it appeared best to defer this matter for the present.

In conclusion, I desire to acknowledge my obligations to Professor H. Newell Martin for his kindness and valuable suggestions.

Vita.

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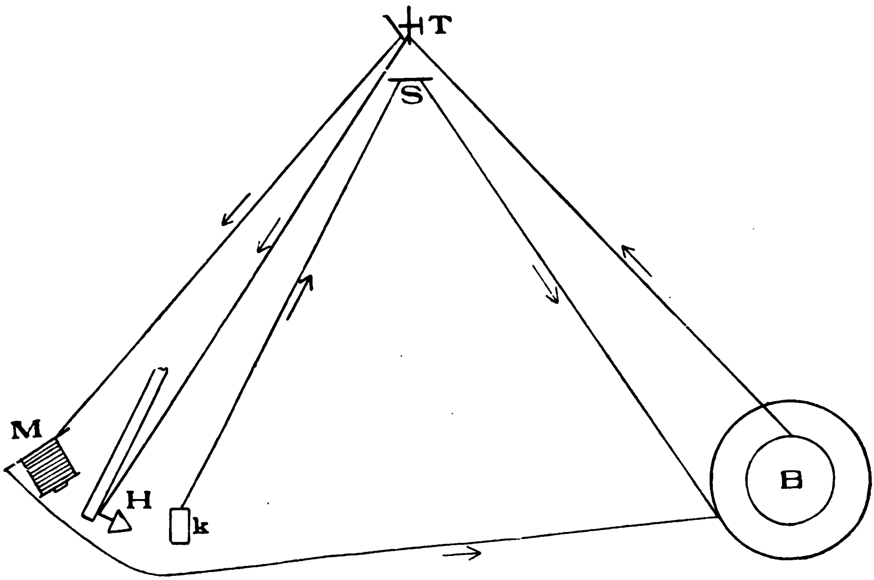
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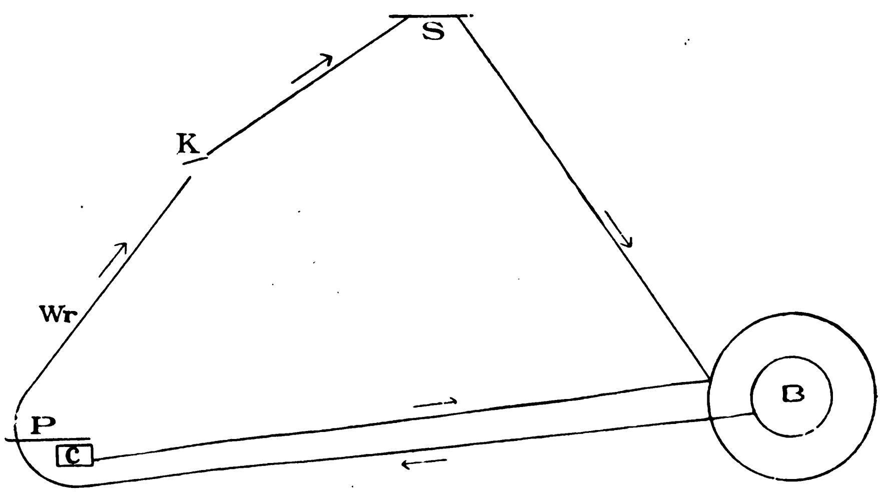
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